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Search for Pair Production of Supersymmetric Top Quarks Mimicking Standard Model Top Event Signatures at CDF

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We present results of the search for the super-symmetric partner of the top quark, the stop quark $\left(\tilde{t}_1\right)$, decaying to a b-quark and chargino $\left(\tilde{\chi}_1^{\pm}\right)$ with the subsequent $\tilde{\chi}_1^{\pm}$ decay into a neutralino $\left(\tilde{\chi}_1^0\right)$, lepton ($\ell$), and neutrino ($\nu$). Using the data sample corresponding to 2.7 fb^{-1} of integrated luminosity, collected with the CDF Detector of the Tevatron $p\bar{p}$ collider, we reconstruct the stop mass of candidate events and set 95% C. L. upper limits on masses of the stop quark, chargino and neutralino and the branching ratio $\mathcal{B}(\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \ell^{\pm}\nu)$.

1. INTRODUCTION AND MOTIVATIONS

Supersymmetry (SUSY) is one of the most plausible extensions to the Standard Model (SM) of particle physics. It naturally solves the problem with quadratically divergent quantum corrections contributing to the Higgs mass. It predicts unification of gauge coupling constants at a common GUT scale, and provides a natural dark matter candidate. SUSY postulates that each of the fundamental SM fermions (bosons) has a boson (fermion) super-partner. To reconcile the super-symmetry with experimental data, SUSY must be broken, and sparticles are expected to be much heavier than their SM partners. Perhaps with an exception of the partner of the top quark (t), the stop quark, whose low mass eigenstate ($\tilde{t_1}$) could be actually lighter than the top quark. It is interesting, that the mass inequality $m_{\tilde{t}_1} \lesssim m_t$ is demanded in the supersymmetric electroweak baryogenesis scenarios [1], which attempt to provide an explanation for the origin of the baryon asymmetry in the Universe.

If the chargino ($\tilde{\chi}_1^{\pm}$) happens to be lighter than the stop quark, the decay $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$ opens and becomes dominant. At the Tevatron stop quarks, if exist, would be produced in pairs with the cross section a factor of ~ 10 smaller than that for the top quarks of the same mass. Assuming that both charginos decay as $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \ell^{\pm}\nu$, cascade decays of stop quarks would produce experimental event signatures with two high-p_T, oppositely charged leptons, two and more jets, and a large missing transverse energy $\not\!\!E_T$. It is interesting, that this event signature is identical to the dilepton final state of $t\bar{t}$ decays. Therefore a small admixture of stop events to the $t\bar{t}$ dilepton events would impact measurements of the properties of the top quark. In particular, it would bias the top mass measurements in the dilepton channel towards lower value relative to those measured in other channels of the $t\bar{t}$ decays. Intriguingly, it is exactly what had been observed in Tevatron experiments. The mass measurements in the lepton+jets and the dilepton channel based on the datasets corresponding to 1 fb^{-1} of integrated luminosity had only 7% chance to yield results more discrepant than those observed [2]. Using a conjecture above this feature could be interpreted as a sign of super-symmetry and it has served as a motivation for the following search.

2. PRELIMINARY EVENT SELECTION AND STOP MASS RECONSTRUCTION

We use data collected with the CDF detector corresponding to 2.7 fb^{-1} of integrated luminosity. Events with a high-p_T (≥ 18 GeV/c) e or μ candidate are identified using the high speed trigger electronics. In the preliminary event selection stop candidate events are required to have two leptons (e or μ), two or more jets with $E_T > 12$ GeV and missing transverse energy $\not\!\!E_T > 20$ GeV. Events are also classified according to availability of a secondary vertex tag (b-tag) [3]. Optimized event selection criteria are determined at the last stage of the analysis.

The kinematic reconstruction of stop events is a challenging task, since in each $\tilde{t}_1\bar{\tilde{t}}_1$ event there are only four particles (2 leptons and 2 b-jets), four-momenta of which are actually measured, while four other particles (2 ν's and 2 massive $\tilde{\chi}_1^0$'s) escape detection, and their existence can only be inferred by an imbalance of transverse energy in the detector. In addition, masses of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ are unknown, and therefore the kinematics of stop events is severely unconstrained. The $\tilde{t}_1\bar{\tilde{t}}_1$ event reconstruction is performed by constructing χ^2-term, which represents the quadratic sum of the differences between the true particle masses and invariant masses of their decay products as measured in the detector and divided by the respective width of the particle. To overcome problems due to unconstrained kinematics, several useful simplifications are made. First, we use $m_{\tilde{\chi}_1^{\pm}}$ as a parameter in the fit and reconstruct stop mass in each event for several values of $m_{\tilde{\chi}_1^{\pm}}$. Second, to avoid the two-fold ambiguity in assigning a b-jet to the respective lepton, we chose the pairing that yields the smallest sum of invariant masses $\sum m_{b\ell}$. This approach identifies the correct pairing in $\sim 90\%$ cases. Third, the pair $\tilde{\chi}_1^0 + \nu$ corresponding to each $\tilde{t}_1$ leg is treated as one massive particle with a large width. Our Monte Carlo studies showed that for a large range of neutralino masses $m_{\tilde{\chi}_1^0} \approx 46 - 90$ GeV, the choice of $m_{\tilde{\chi}_1^0+\nu} = 75$ GeV and $\Gamma_{\tilde{\chi}_1^0+\nu} = 10$ GeV works reasonably well. Using all of these assumptions the sums of four-momenta $\tilde{\chi}_1^0 + \nu$ corresponding to each stop leg are still not uniquely identified. Therefore we integrate over the phase space of all possible solutions weighted by the χ^2-term. The reconstructed mass of the stop quark is then given by $m_{\tilde{t}_1}^{rec} = \int m_{\tilde{t}_1}^{rec,i} e^{-\chi_i^2} dS_i / \int e^{-\chi_i^2} dS_i$

3. BACKGROUNDS MODELING, SYSTEMATICS UNCERTAINTIES AND LIKELIHOOD FIT

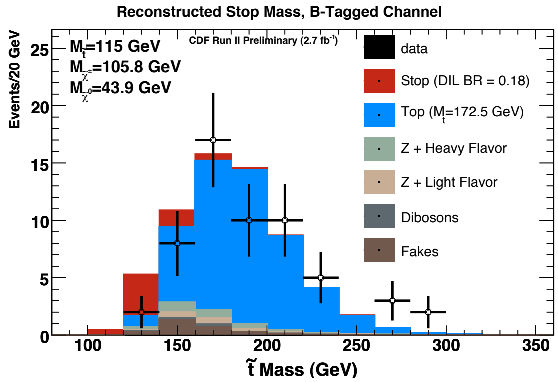
The dominant SM process that contributes to the dilepton + jets event signature is $t\bar{t}$. Other SM processes include Z/γ^*+ jets, diboson production, and $W+$ jet events, where one jet is misidentified as a lepton. We use the PYTHIA [4] Monte Carlo (MC) event generator to simulate $\tilde{t}_1\bar{\tilde{t}}_1$, $t\bar{t}$ and diboson processes. Z/γ^*+ associated jet production is simulated with the ALPGEN [5] matrix element generator followed by parton fragmentation and hadronization by PYTHIA. To model $W+$ jets events we exploit data events with one fully identified lepton plus a lepton-like candidate that must fail certain lepton ID requirements. A fake rate probability for such an object to be identified as a lepton is estimated from a large jet-triggered data sample, and then applied to each data lepton + fake event. We validate the modeling of dilepton events in the control regions corresponding to low $\not\!\!E_T$, zero and one jet bins and same-sign charged leptons.

Imperfect knowledge of various experimental and theoretical parameters leads to systematic uncertainties which degrade our sensitivity to $\tilde{t}_1\bar{\tilde{t}}_1$ signal. The dominant systematic effect is due to the uncertainties in the NLO theoretical cross sections for $\tilde{t}_1\bar{\tilde{t}}_1$ and $t\bar{t}$ production. These uncertainties come from two sources: due to renormalization and factorization scale (11% and 7% for $\tilde{t}_1\bar{\tilde{t}}_1$ and $t\bar{t}$ respectively) and due to parton density functions (14% and 7%) [6, 7]. We assume that the first one is uncorrelated between two sources, while the latter one is fully correlated. The $t\bar{t}$ background is normalized to the theoretical cross section value at the top mass world average of 172.5 GeV/c^2 [8] that is dominated by the measurements in the lepton + jets channel of $t\bar{t}$ decays.

The experimental uncertainties include those due to jet energy scale (3%), b-tagging probability (5%), lepton ID and trigger efficiencies (1%), initial/final state radiation, and integrated luminosity (6%) which is applied to MC-based background estimates. Normalization of W and $Z+$ jets events is determined from data. Uncertainty on W+jets is driven by the uncertainties in the fake rate predictions (30%), while uncertainty on $Z+$ jets is due to mis-modeling of the high-$\not\!\!E_T$ and jet multiplicity distributions and heavy-flavor corrections (16%).

We employ the modified frequentist method, CL_s[9], that represents binned likelihood fits to the reconstructed stop mass of data under the hypothesis of the SM background only and the hypothesis of signal plus background. The fits are performed simultaneously in the channel with at least one b-tagged jet and the channel with no b-tags. The systematic uncertainties for both signal and background, described above, enter the fit as Gaussian constrained nuisance parameters. The shape uncertainties are accounted by allowing templates shapes to change ("morph") according to the values of the nuisance parameters.

The sensitivity of the likelihood fit (including all of the systematic uncertainties) to the stop signal is tested for various event selection criteria imposed separately for b-tagged and non-tagged channel. These criteria are allowed to vary using an algorithm based on biological evolution. Selection cuts yielding poor sensitivity to the signal are culled, while those improving sensitivity are bred together until reaching a plateau. Optimizing directly for the best 95% C.L. limit has advantages with respect to event cuts selected based on some intermediate figure of merit.



Events per 2.7 fb^{-1} in the signal region with ≥ 1 b-tag.

Source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
top	11.3 ± 1.8	10.4 ± 1.6	26.7 ± 3.8	48.4 ± 7.0
Z/γ^*+HF	1.3 ± 0.3	0.9 ± 0.2	0.4 ± 0.1	2.6 ± 0.5
Z/γ^*+LF	0.9 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	1.7 ± 0.1
diboson	0.2 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.6 ± 0.1
fake lepton	0.5 ± 0.2	0.5 ± 0.1	1.8 ± 0.5	2.8 ± 0.8
Total	14.2 ± 2.0	12.4 ± 1.6	29.4 ± 3.8	56.0 ± 7.3
stop	1.1 ± 0.3	1.4 ± 0.4	3.0 ± 0.7	5.5 ± 1.2
Data	15	12	30	57

Table I: The reconstructed stop mass distribution (left) and the table of expected event yields (right) from Standard Model sources and $\tilde{t}_1\bar{\tilde{t}}_1$ at the 95% C.L. exclusion limit(right).

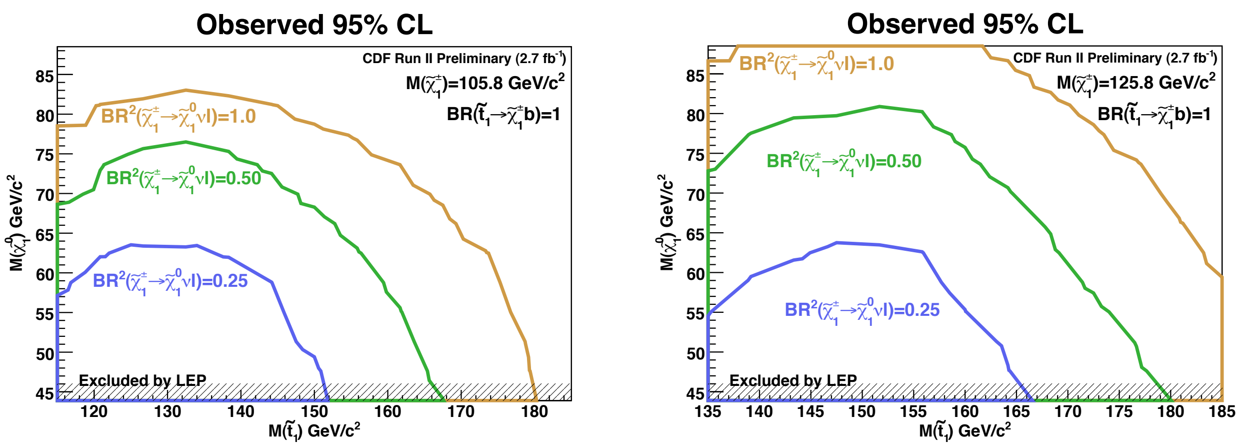


Figure 1: Observed 95% C.L. limits on the $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{t}_1}$ for several values of $\mathcal{B}(\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \ell^\pm \nu)$, and assuming $m_{\tilde{\chi}_1^\pm}$ =105.8 GeV/c^2 (left) and $m_{\tilde{\chi}_1^\pm}$ =125.8 GeV/c^2 (right). Universality of e, μ, and τ in the $\tilde{\chi}_1^\pm$ decays is assumed.

4. RESULTS

As can be seen from Table I, the data is consistent with the Standard Model. The fit to the reconstructed stop mass distribution reveals no evidence of $\tilde{t}_1\bar{\tilde{t}}_1$ production, and thus we proceed and place 95% CL limits on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{t}_1}$ for several values of branching ratio $\mathcal{B}(\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \ell^\pm \nu)$ and $m_{\tilde{\chi}_1^\pm}$. The results are presented in Figure 1.

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